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TURBINE PUMP OF LIQUID FUEL ROCKET ENGINE,(U)

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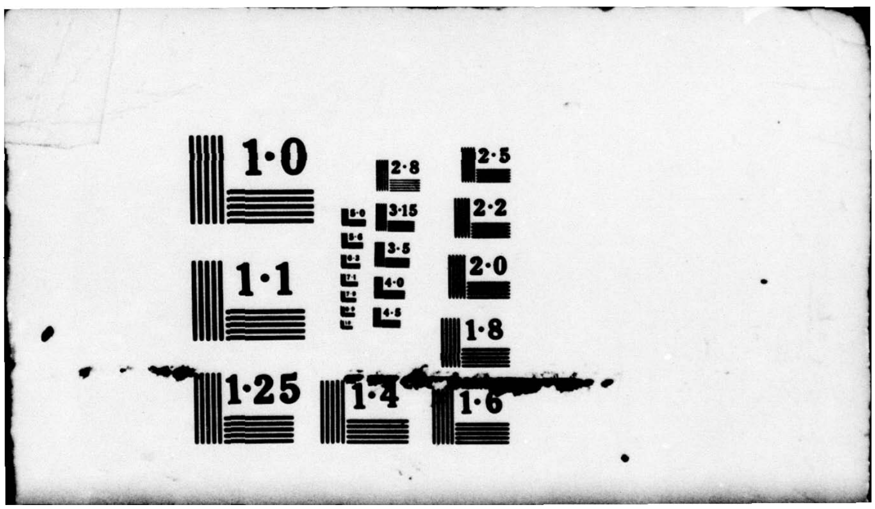
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by

Hsu Chih Ning

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TURBINE PUMP OF LIQUID FUEL ROCKET ENGINE

Hsu Chih Ning

The turbine pump is an important element of the hydraulic transporting system of propellant in a liquid fuel rocket engine. This article introduces to the reader the function, structure and the working principles of a turbine pump.

The transport and feeding system for the propellant in a liquid rocket engine mainly consists of the gas pressure and hydraulic pressure models. The propellant includes the oxidant, the combustant and the natural fuel -- customarily known as the constituents. An essential component of the hydraulic transport system is the turbine pump.

The propellant from the storage tank is pressurized by the turbine pump and then fed into the thrust chamber through pipes according to specified flow rate, pressure and procedure. See Fig. 1. The power required in pressurizing the propellant is supplied by the turbine. The other component of the turbine-pump is the pump. A more descriptive name of the

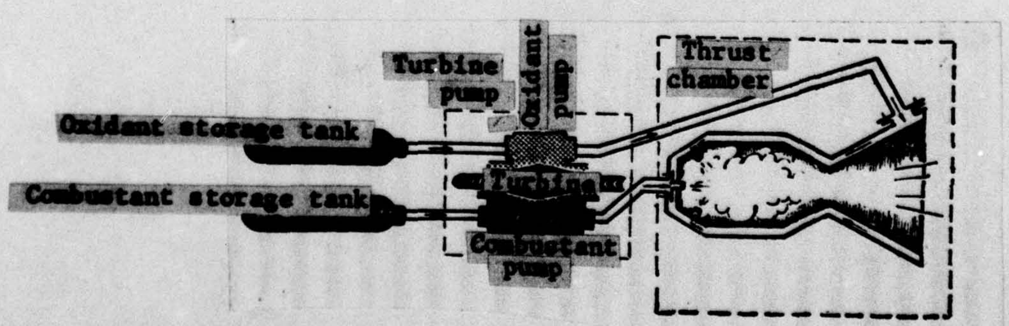

Fig. 1 Liquid fuel rocket engine

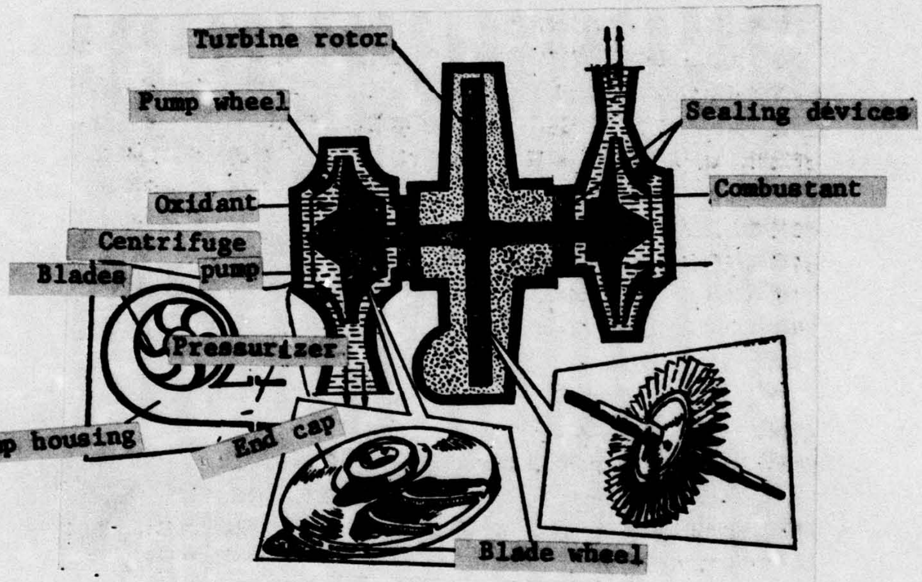

Fig. 2 Schematic diagram of the turbine pump

turbine pump is perhaps "Turbine-pump linkage assembly." Fig. 2 depicts the structure of a turbine pump and its main components.

<u>The turbine pump rotor</u>: This consists of the turbine rotor and the two pump wheels at its two ends. The gas produced by the combustant gas generator turns the turbine rotor and rotates the two pump wheels, and thereby pressurizes the propellant constituents.

<u>The shell body</u>: The shell body houses and supports the rotor. The shell of the rotor joins with the shell body of the two pumps and other components, such as the combustant gas generator, which are attached to the body.

The seals: The seals are located at four places where the intakes of the two pumps are joined to the rotor housing and the pump housing. The seals divide the space in the turbine pump housing into a turbine chamber and two pump chambers isolated from each other. This arrangement separates the two different constituents from the combustant gas in the turbine. It also prevents the constituents at higher pressure after the pressurization by the pump from flowing back to the intake of the pumps.

Pressurization by Centrifuge Pump

A variety of pumps could have been used if considerations are given only to the pressure and output flow rate. However, the pump used in the turbine pump assembly is usually the centrifuge type (see Fig. 2), mainly because of the many advantages of the centrifuge pump: large flow rate per stage, high ability of pressurization, functions under high rotary speed, compact dimension and light weight, and also the relative ease of manufacturing.

The pump wheel of the centrifuge pump consists of the end cap and the blade wheel. Its working principles are illustrated in Fig. 3. The constituents enter the pump wheel in an axial direction and turn into the channels between the blades. They are then forced to flow in outward directions under the centrifugal force while confined in the channels and turning together with the blade wheel. Under the pump's high speed of rotation, the flow speed of the constituents upon entering the blade wheel (8 m/sec) is raised to a high speed of about 50-100 m/sec upon leaving the blades. The constituents have therefore gained kinetic energy from the rotating blades.

The propellant flowing away from the blades at a high speed is collected by the housing. However, the collected propellant is not yet ready to be

fed into the thrust chamber. Propellant of a high flow speed has too low a pressure to vaporize and combust properly in the combustion chamber, thereby reducing the thrust produced by each kilogram of fuel. In order to improve the situation, a cone-shaped pressurizer of rather simple structure and low efficiency can be installed on the housing. Basically, it is a cone-shaped straight thoroughfare which reduces the constituent flow speed to about 6-12 m/sec and in the process increases the pressure to a maximum value at the output of the cone pressurizer. This pressure is known as the output pressure of the pump in contrast to the intake pressure of the pump under which the constituents enter the pump. The entire process from intake to output is called the "pump-to-constituent pressurization."

Vapor Corrosion of Centrifuge Pump

An efficient measure to take in reducing the weight and volume of the centrifuge pump is to increase its rotary speed and thereby raising its pressurization ability and flow rate. This is evidenced by the ever increasing rotation speed observed in the development of turbine pumps. The rotation speed has been increased by ten-fold to the 30,000 rev/min today since the V-2 missile used by Germany in World War II. Further increase of rotary speed encounters a serious drawback -- the vapor corrosion.

Vapor corrosion was first discovered on the propeller blades of high speed boats. Peeling of metal of pin-hole size or over larger area spots has been observed on the blade surfaces. Vapor corrosion has now become a general problem with the wide use of high speed machinery in the delivering of fluids encountered in the realms of aviation and others. To understand how the vapor corrosion comes about, we have to start with the familiar

phenomenon of the vaporization of liquids.

If we pour some liquid in a cup, seal it off and store in a constant-temperature environment, we will first notice that the liquid level drops as the liquid vaporizes and then the surface will maintain a constant level after a certain amount of time. The vaporization process has not stopped, on the contrary, it is proceeding as before. However, within unit time, the number of molecules escaping from the liquid is equal to the number of molecules going from the vapor back to the liquid surface and a dynamic equilibrium is reached. If the ambient temperature is raised at this time, the equilibrium will be destroyed: the level will be dropping and the amount of vapor above it increasing until a new equilibrium is reached. Under the dynamic equilibrium at any temperature, the pressure exerted by the vapor is the saturation vapor pressure of the liquid at that temperature.

If high pressure air is introduced into the closed container, the liquid level will rapidly rise to the original level when it was poured into the cup. This example illustrated the fact that when the pressure of the liquid exceeds the saturation vapor pressure at a given temperature, vaporization will be inhibited and the vapor will quickly condense back to the liquid state. One should never underestimate the damage caused to the pump by such seemingly simple phenomena -- they are precisely the cause of vapor corrosion.

In a pump working under the conditions of high rotation speed and large flow rate, the liquid constituents enter the pump wheel at a high speed. At a minimum effective crossectional area of the pump wheel, the flow speed is at a maximum and the pressure is at a minimum. If the liquid pressure at this cross section is lower than the saturation vapor pressure at the given temperature, the constituents will vaporize and form bubbles.

As soon as the bubbles appear, they are swept forward by the continuous flow of liquid to a location where the flow rate is slower and the pressure is higher. When the pressure is higher than the saturation vapor pressure, the bubbles will condense into liquid. Another fact to consider is that the volume of vapor bubbles is much greater than the volume of liquid of equal weight. For example, the weight of one cubic meter of water vapor at 4° C is 6.4 grams whereas a cubic meter of water weighs one ton. A ton of water vaporized completely at 4° C will occupy a volume of 156.25 cubic meters. Therefore, the sudden condensation of vapor left a large empty volume which is then filled by the oncoming fluid at a high speed. This causes a tremendous hydraulic impact and the local pressure can be several thousand atmospheres. If the pump is working under a steady state, vapor bubbles will be continuously generated and then will condense at a rapidly repeating pace of several tens of thousand times per second. This high pressure hydraulic impact at high frequency eventually causes the peeling of metal. Furthermore, liquids with an oxygen content tend to decompose and produce oxygen atoms upon vaporization. Such primary oxygen atoms combine with metal and cause rust corrosion on the metal surface. Rust corrosicn is even more serious at places where the metal surface is peeling. The combined effects of rust corrosion and hydraulic bombardment cause damage to the pump parts in very short periods of time. When the situation is less chronic, needle shaped or spotty peeling may result in vibrations and noise of the entire pump and impair the normal function. In cases of severe vapor corrosion, vapor bubbles may block the channels in the pump wheel and prevent the supply of constituents to the thrust chamber. A stalled engine can cause serious accidents. The phenomenon of vapor corrosion is indeed a grave problem which hinders the

improvements of pump characteristics and threatens their safe operation.

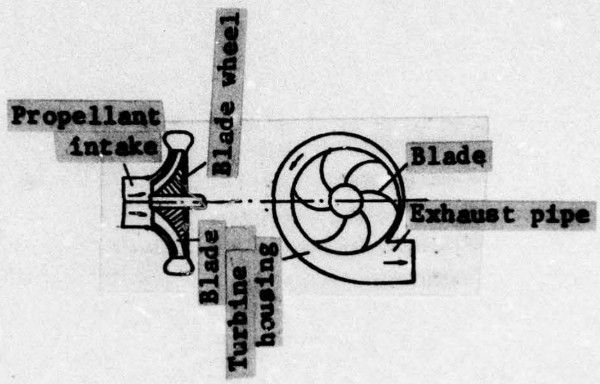

Fig. 3 The function of a centrifuge pump

Many nations are engaged in research to improve the anti-corrosion capability and to solve the problem of vapor corrosion. To date, the practice is usually adding a "pre-rotate pressurizer" at the intake to increase the intake pressure and slow down or stop the vapor corrosion. So far the research has not been matured in either theoretical or practical approach.

How Does the Turbine Generate Power?

The turbine discussed here works on the same principles of the aviation jet turbine engine. Since the power demand here is smaller, single stage turbines are employed, and impact type blades of relatively low efficiency and good mechanical properties are generally installed on the rotor. The cross section of such blades and the function principles are illustrated in Fig. 4. The combustant gas required by the turbine is produced in the combustion gas generator; natural fuel decomposes in the generator and becomes high temperature and high pressure combustant gas which accelerates through the nozzle and rushes toward the blade channels at some specified

direction. The channels formed by impact blades have the following characteristics: as the gas flows through the channels, its direction is forced to change while its speed is basically unchanged. Thus, the channel exerts a force on the gas and the reaction force by the gas on the channel causes the rotor to turn at a high speed and produces power. Waste gas after the process is expelled through the exhaust pipe. The power of the turbine can be controlled by varying the inner diameter of the throttle ring which governs the flow rate and pressure under which the native fuel is entering the gas generator.

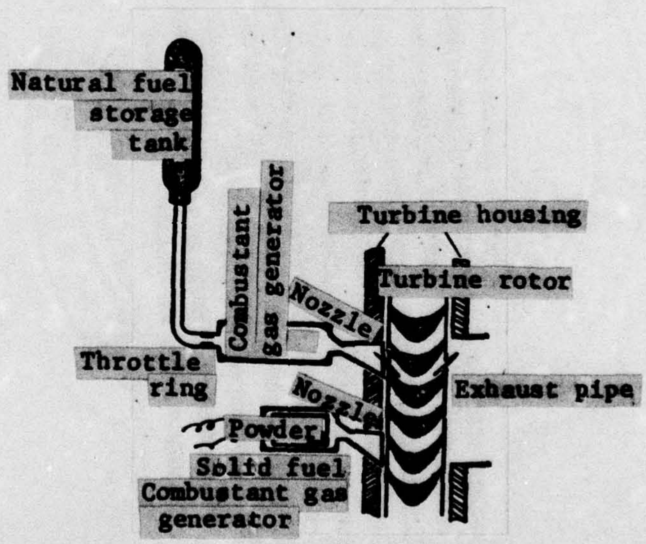

Fig. 4 Working principle of the turbine

Start Acceleration of the Turbine Pump

Start-acceleration-time is the time required for the turbine to reach some specified state. This quantity characterizes the merit of the acceleration ability.

During the start acceleration time, the guided missile is still on the ground since the specified thrust has not been produced by the thrust chamber. If this time is too long, a great amount of fuel is consumed (especially for large guided missiles). Furthermore, as the missile is being surrounded by large amounts of high temperature gas, there is the danger of burning. The start acceleration time is even more critical for anti-aircraft missiles because of the high speed of aircraft . The missile needs to enter the trajectory rapidly and accurately so that the serious results of missing the enemy aircraft can be avoided. The demand on acceleration time of turbines is usually high -- a few tenths of one second.

Such challenging demands cannot be met using the combustion gas generator alone. Since the chemical property of the natural fuel is unstable and decomposes readily, the storage tank can only be opened at the start of the engine to allow the fuel to be fed into the gas generator through pipes. Thus, the flow rate and pressure will reach specified values only after a certain amount of time, short as it may be, still longer than the required starting time. This is rather analogous to the water faucet. Water flow rate will not reach its maximum instantly even if the faucet is turned to wide open very rapidly. If a long hose is attached to the faucet, the lag in flow rate and pressure is even more evidently observed. In order to make up for the lag in the combustion gas generator upon starting and improve the acceleration, a solid fuel combustion gas generator can be installed on the engine. The generator consists of the powder chamber (for storing the solid fuel or powder) and the nozzle. (See Fig. 4) Upon starting the engine, the powder is ignited with electric sparks and a combustant gas of high pressure and temperature is produced with practically no delay since the combustion of the powder

is explosive and extremely fast. The produced gas then accelerates through the nozzle and blows onto the turbine at specified directions to accelerate the turbine rapidly. The solid fuel gas generator can only supply gas to the turbine for a very short period of time, but the liquid fuel gas generator will be in its operating condition before the solid generator runs out. Hence, the two generators work in parallel for a short period of time and the acceleration of the turbine is completed at the end of the parallel operation. After that, the liquid fuel generator alone is used to supply the gas and keeps the turbine pump under specified operating conditions. The two generators are like the two athletes in a relay race; being the first baton, the solid generator does the take-off acceleration and the liquid generator then takes over and finishes the run at an even speed. From start to the exchange of baton is completed within the desired start acceleration time.

What is Required of the Turbine Pump?

In addition to the three main requirements discussed above -- delivery of constituents at specified flow rate and pressure, anti-vapor-corrosion capability and fast start acceleration -- there are other demands from a different context:

It is part of an object flying in the sky, therefore it should have light weight, small volume and high reliability. Since it is also part of something which will be used "once only," it ought to be economical and to have good mechanical properties. For these reasons, impact style blades and cone pressurizers are still widely used even though their efficiencies are low.

Guided missiles are expected to fly high, fast and far; their rocket engines are required to deliver huge thrust. In some large engines, the flow rate of constituents may reach half of a ton per second, and the output pressure of the pump as high as several hundred atmospheres. The primary challenge placed upon the turbine pump is to pressurize the constituents at enormous flow rate to such high pressure and feed them into the thrust chamber at a controlled steady pressure. This mission alone, under the other constraints discussed above, is quite a feat. Furthermore, of the many different constituents being used today, each has its own unique physical and chemical properties: some are strongly corrosive, some hazardous to human health, and others highly explosive (liquid oxygen, for example, may explode while being transferred into the storage tank or while being pressurized). All these restrictions further complicated the design of the pump and made the safety requirements more stringent and difficult.

In summary, the turbine pump works under the unfavorable conditions of high temperature, high pressure, heavy load, serious corrosion and small safety factor of material. Numerous problems relevant to these restrictions need to be attacked and solved.

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